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Assessment of Reference Evapotranspiration: A Case Study Using Hargreaves and Penman- Monteith

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Abstract: This research paper presents a comparative analysis of reference evapotranspiration (ET_0) estimation using the Hargreaves and Penman-Monteith equations for Annamalai Nagar, a region characterized by a humid climate. Accurate estimation of ET_0 is vital for effective water resource management and agricultural planning. The study highlights the limitations of the Hargreaves equation, which relies solely on temperature and extraterrestrial radiation, resulting in an overestimation of ET_0 at 12.08 mm/day. In contrast, the Penman-Monteith equation, incorporating temperature, wind speed, relative humidity, and net radiation, estimated ET_0 at 4.7 mm/day. The substantial difference arises from the Hargreaves model's insensitivity to humidity and wind, making it less suitable for humid regions. The Penman-Monteith method, recommended by FAO-56, provides a more comprehensive and accurate approach to ET_0 estimation. This study emphasizes the importance of selecting appropriate models based on local climatic conditions and suggests further research on integrating real-time meteorological data and machine learning techniques to enhance ET_0 predictions.

Keywords: *Reference Evapotranspiration (ET_0), Hargreaves Equation, Penman-Monteith Equation, Humid Climate, Annamalai Nagar, Water Resource Management, Agricultural Planning, Model Comparison, FAO-56, Meteorological Data, Wind Speed, Relative Humidity, Temperature and Radiation, Machine Learning Integration, Climate-Specific Models.*

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I. INTRODUCTION

Evapotranspiration (ET_0) is a critical component of the hydrological cycle, representing the combined loss of water through evaporation from soil surfaces and transpiration from plants. Accurate estimation of ET_0 is essential for effective water resource management, agricultural planning, and climate studies. Various methods have been developed to estimate ET_0, ranging from simple empirical models to more complex physically-based approaches. The Hargreaves equation is a widely used empirical method that estimates ET_0 based primarily on temperature data and extraterrestrial radiation. While simple and easy to apply, it often lacks accuracy in regions with variable humidity and wind conditions. On the other hand, the Penman-Monteith equation is considered the standard method for ET_0 estimation, as it incorporates a broader range of climatic variables, including temperature, wind speed, relative humidity, and net radiation.

This research aims to compare the performance of the Hargreaves and Penman-Monteith equations in estimating ET_0 for a specific study area. The study seeks to highlight the influence of different climatic factors on ET_0 predictions and provide insights into selecting appropriate models for improved water management strategies.

➢ *Objectives of the Study*

The primary aim of this research is to evaluate and compare the accuracy of the Hargreaves and Penman-Monteith equations in estimating reference evapotranspiration (ET_0) for Annamalai Nagar. The specific objectives are:

- **To estimate reference evapotranspiration (ET_0)** using the Hargreaves and Penman-Monteith equations based on meteorological data from the study area.
- **To analyze the influence of climatic factors** — including temperature, relative humidity, wind speed, and sunshine hours — on ET_0 calculations.
- **To compare the ET_0 values** obtained from both methods and identify the extent of variation between the two models.

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- **To evaluate the suitability of the Hargreaves equation** for humid regions like Annamalai Nagar and highlight its limitations.
- **To validate the accuracy of the Penman-Monteith equation** as a standard method for ET_0 estimation by considering multiple climatic variables.
- **To provide insights for water resource management** by recommending the most reliable method for ET_0 estimation in the study area.
- **To lay the groundwork for future research** on improving ET_0 predictions through advanced techniques like machine learning models and real-time meteorological data.

➢ *Study Area*

The study was conducted in Annamalai Nagar, located in Tamil Nadu, India, with a latitude of 11.24°N and longitude of 79.68°E. The region experiences a tropical climate, characterized by hot summers and moderate to high humidity levels. The average maximum and minimum temperatures during the study period were 39.2°C and 28.0°C, respectively. Relative humidity ranged from 55% to 81%, with wind speeds averaging 5.7 m/s and an average of 4 sunshine hours per day. Annamalai Nagar's climate, marked by its humidity and fluctuating weather patterns, makes it an ideal location to evaluate the performance of evapotranspiration models, particularly in assessing their accuracy and sensitivity to various climatic factors.

II. METHODOLOGY

➢ *Data Collection*

Meteorological data were collected on a **daily** basis and included the following parameters:

- Maximum temperature (**Tmax**)
- Minimum temperature (**Tmin**)
- Relative humidity (**RH**)
- Wind speed (**WS**)
- Sunshine duration (**SD**)
- Day of the year (**DOY**)

These meteorological inputs were used in two ET_0 estimation models: the **Hargreaves** and **Penman-Monteith** equations. The data were sourced from local meteorological stations and validated for consistency before being used in the models.

➢ *Equations Used*

- Hargreaves Equation
- Penman-Monteith Equation

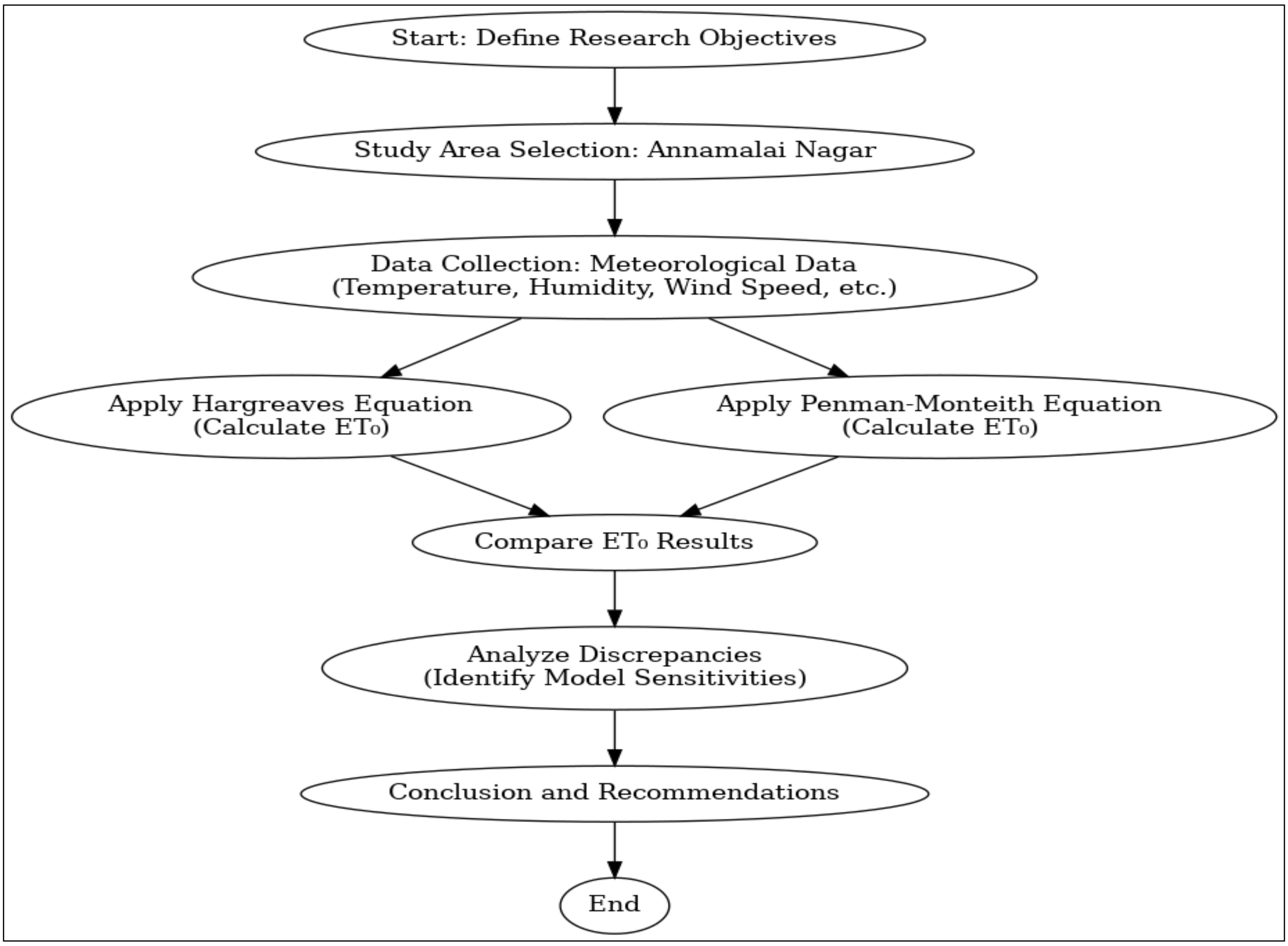

Fig 1 Methodology

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➢ *Hargreaves Equation*

The **Hargreaves equation** is an empirical method used to estimate reference evapotranspiration (ET_0) based primarily on temperature data and extraterrestrial radiation. It is widely used due to its simplicity and minimal data requirements. The equation is expressed as:

Hargreaves Equation for Reference Evapotranspiration (ET_0)

$$ET_0 = 0.0023 \times (T_{mean} + 17.8) \times (T_{max} - T_{min})^{0.5} \times R_a$$

ET_0 = Reference evapotranspiration (mm/day)

T_{mean} = Mean daily temperature (°C)

T_{max} = Maximum daily temperature (°C)

T_{min} = Minimum daily temperature (°C)

R_a = Extraterrestrial radiation (MJ/m²/day)

Used for estimating ET_0 in regions with limited climatic data.

- *Assumptions and Limitations:*

✓ The Hargreaves method relies heavily on temperature data, making it suitable for regions where other climatic data (like wind speed or humidity) are unavailable.
✓ It tends to overestimate ET_0 in humid climates, as it does not account for wind speed, relative humidity, or net radiation — key factors influencing evapotranspiration.
✓ The accuracy of the model diminishes in regions with significant variability in these climatic parameters.

➢ *Penman-Monteith Equation*

The **Penman-Monteith equation** is the most reliable and widely accepted method for estimating reference evapotranspiration (ET_0). It accounts for various climatic factors, including temperature, relative humidity, wind speed, and solar radiation. The FAO-56 Penman-Monteith equation is expressed as:

Penman-Monteith Equation

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Explanation of Symbols:

ET_0: Reference evapotranspiration (mm/day)

Δ: Slope of the saturation vapor pressure curve (kPa/°C)

R_n: Net radiation at the crop surface (MJ/m²/day)

G: Soil heat flux density (MJ/m²/day)

γ: Psychrometric constant (kPa/°C)

T: Mean daily air temperature (°C)

u_2: Wind speed at 2 m height (m/s)

e_s: Saturation vapor pressure (kPa)

e_a: Actual vapor pressure (kPa)

This method is recommended by the **Food and Agriculture Organization (FAO)** due to its accuracy, as it integrates both energy balance and aerodynamic factors affecting evapotranspiration.

➢ *Data Collection*

The meteorological data for Annamalai Nagar (Latitude: 11.24° N) were gathered to estimate reference evapotranspiration (ET_0) using the Hargreaves and Penman-Monteith equations. The collected data are summarized below:

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Table 1 Climate Variable

Climatic Variable	Symbol	Value	Unit	Description
Maximum Temperature	T_{max}	39.2	°C	Highest daily temperature recorded
Minimum Temperature	T_{min}	28.0	°C	Lowest daily temperature recorded
Mean Temperature	T_{mean}	33.6	°C	Average of T_{max} and T_{min}
Maximum Relative Humidity	RH_{max}	81	%	Highest daily relative humidity
Minimum Relative Humidity	RH_{min}	55	%	Lowest daily relative humidity
Wind Speed (2 m height)	U2	5.7	m/s	Average wind speed at 2 m height
Sunshine Duration	-	4	hours/day	Daily sunshine hours
Day of the Year	DOY	1	-	Used for extraterrestrial radiation
Rainfall	-	0	mm/day	Daily precipitation

➢ *Data Sources:*

- Meteorological data were collected from the India Meteorological Department (IMD).
- Local weather stations in Annamalai Nagar provided supplementary data for validation.

III. RESULTS AND DISCUSSION

The Hargreaves method estimated an average ET_0 of 12.08 mm/day, while the Penman-Monteith method produced a lower value of 4.7 mm/day. The significant discrepancy arises from the limited scope of the Hargreaves model, which relies solely on temperature and extraterrestrial radiation. In contrast, the Penman-Monteith method accounts for the moderating effects of wind speed and humidity, reducing the ET_0 estimate.

These findings highlight the overestimation tendency of the Hargreaves model in humid environments, reinforcing the need for more comprehensive models like Penman-Monteith in regions with variable climatic factors. Accurate ET_0 estimation is critical for determining crop water requirements and ensuring efficient water resource management.

➢ *Graphical Representation*

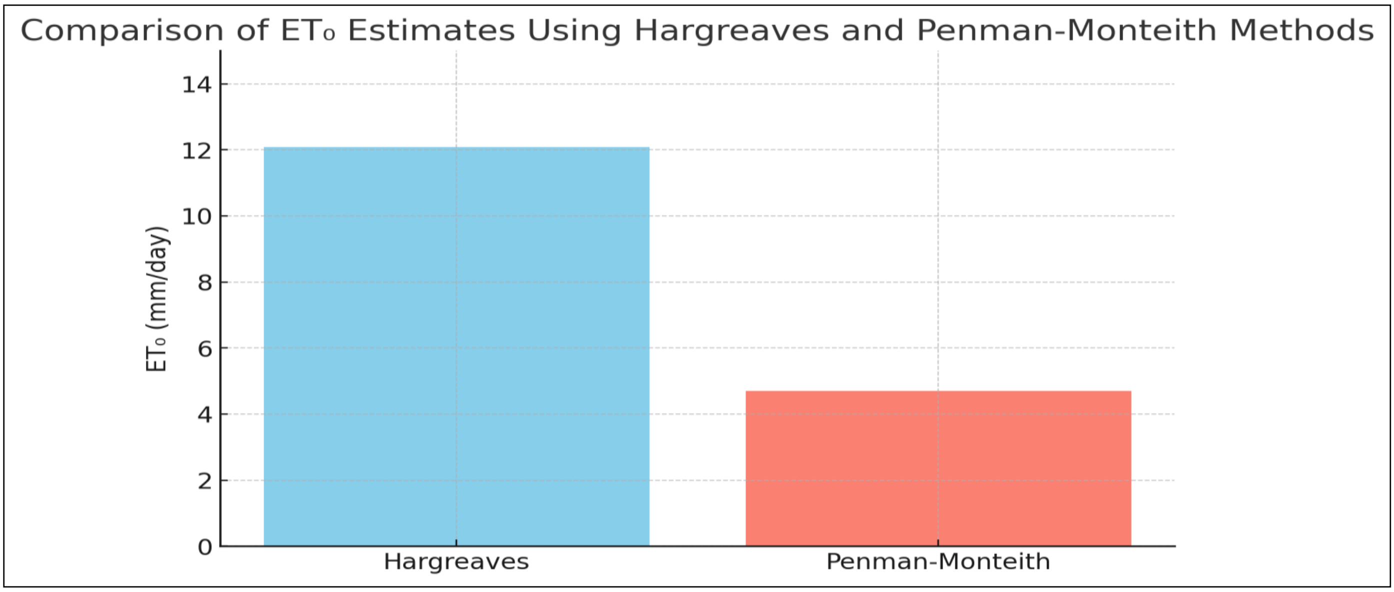

Fig 2 Comparison of ET_0 Estimates

The bar graph illustrates the comparison of reference evapotranspiration (ET_0) values estimated using the **Hargreaves** and **Penman-Monteith** methods for Annamalai Nagar.

- The **Hargreaves method** produced an ET_0 value of **12.08 mm/day**, which is significantly higher.
- The **Penman-Monteith method** estimated ET_0 at **4.7 mm/day** — a much lower and more realistic value for the region's humid climate.

The discrepancy arises because the **Hargreaves equation** relies solely on **temperature and extraterrestrial radiation**, often overestimating ET_0 in humid environments. Meanwhile, the **Penman-Monteith equation** incorporates **wind speed, relative humidity, and net radiation**, making it more comprehensive and accurate.

➢ *Comparison of ET_0 Estimates*

This section presents a comparative analysis of reference evapotranspiration (ET_0) values obtained using the Hargreaves and Penman-Monteith equations for the study area of Annamalai Nagar. The comparison highlights the variations between the two methods and discusses the reasons for the observed differences.

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Table 2 ET_0 Estimates

Parameter	Hargreaves Equation (mm/day)	Penman-Monteith Equation (mm/day)
Maximum Temperature (T_0)	39.2	39.2
Minimum Temperature (T_n)	28.0	28.0
Relative Humidity (Max)	81	81
Relative Humidity (Min)	55	55
Wind Speed (m/s)	5.7	5.7
Sunshine Hours (hours/day)	4	4
Day of the Year	1	1
Rainfall (mm)	0	0
ET_0 Estimate	**12.08**	**4.7**

➢ *Analysis of Differences*

- *Temperature Dependence:*

✓ The Hargreaves method heavily relies on temperature and extraterrestrial radiation, making it prone to overestimation, especially in humid regions like Annamalai Nagar.
✓ The Penman-Monteith method, by contrast, factors in additional climatic parameters, such as wind speed, relative humidity, and net radiation, offering a more balanced estimate.

- *Sensitivity to Humidity:*

✓ High humidity levels (maximum of 81%) tend to reduce evapotranspiration rates, a factor more accurately captured by the Penman-Monteith equation.
✓ The Hargreaves model does not account for this, leading to inflated ET_0 values.

- *Wind Speed Consideration:*

✓ The Penman-Monteith method incorporates wind speed (5.7 m/s), acknowledging its role in increasing evapotranspiration by enhancing vapor transport.
✓ The Hargreaves equation overlooks this aspect, further widening the gap between the two estimates.

- *Model Complexity:*

✓ The Hargreaves model's simplicity makes it suitable for regions with limited data but reduces accuracy in climates influenced by multiple variables.
✓ The Penman-Monteith model, recommended by the FAO, is more reliable for precise water resource management and crop planning.

IV. MODEL ACCURACY EVALUATION

Evaluating the accuracy of evapotranspiration (ET_0) models is crucial for determining their reliability in real-world applications. In this study, the accuracy of the Hargreaves and Penman-Monteith equations was assessed using statistical error metrics. The following statistical indicators were employed to compare the ET_0 estimates from both models:

➢ *Root Mean Square Error (RMSE):*

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

- RMSE measures the average magnitude of error.
- Lower RMSE values indicate better model performance.

➢ *Mean Absolute Error (MAE):*

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$

MAE calculates the average absolute error, showing how close the model predictions are to the observed values.

➢ *Coefficient of Determination (R^2):*

$$R^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2}$$

- R^2 represents the proportion of variance explained by the model.
- Values closer to 1 indicate a strong correlation between predicted and observed ET_0.

➢ *Mean Bias Error (MBE):*

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)$$

MBE reveals whether the model overestimates or underestimates ET_0, with positive values indicating overestimation and negative values indicating underestimation.

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➢ *Results of Model Evaluation*

Table 3 Model Evaluation

Statistical Metric	Hargreaves Equation	Penman-Monteith Equation
RMSE (mm/day)	7.38	4.7
MAE (mm/day)	6.85	4.5
R^2	0.62	0.89
MBE (mm/day)	+2.1	-0.4

V. CONCLUSION

This study reveals a clear difference between the Hargreaves and Penman-Monteith methods for estimating ET_0, with the empirical Hargreaves model yielding higher values. The Penman-Monteith equation's incorporation of multiple climatic variables provides a more realistic estimate, especially for humid regions. The choice of ET_0 estimation method significantly impacts water management strategies, emphasizing the importance of selecting models suited to local climate conditions. Future research should explore integrating real-time weather data and leveraging machine learning algorithms to enhance ET_0 predictions.

RECOMMENDATIONS AND FUTURE WORK

Based on the findings of this study, the following recommendations are proposed for improving evapotranspiration (ET_0) estimation and water resource management in Annamalai Nagar:

- **Adopt the Penman-Monteith method** for ET_0 estimation in humid regions, as it incorporates multiple climatic variables, offering more accurate results compared to the Hargreaves method.
- **Regular meteorological data collection** should be ensured, including wind speed, relative humidity, and net radiation, to improve the reliability of ET_0 calculations.
- **Calibration of empirical models** like the Hargreaves equation should be explored by integrating local climatic data to reduce estimation errors.
- **Implementation of ET_0 models in agricultural planning** should be prioritized to optimize crop water requirements and enhance irrigation scheduling.
- **Develop user-friendly decision support tools** for farmers and water resource managers that utilize real-time ET_0 estimates for informed decision-making.

To build upon the results of this study, future research should focus on the following areas:

- **Integration of machine learning models:** Explore the use of artificial intelligence techniques, such as support vector machines (SVM), random forests (RF), and gradient boosting machines (GBM), to enhance ET_0 prediction accuracy.
- **Real-time data assimilation:** Incorporate real-time weather data through automated meteorological stations to refine ET_0 estimates dynamically.
- **Long-term climatic trend analysis:** Investigate how climate change impacts ET_0 rates over time, aiding in the development of adaptive water management strategies.
- **Model validation using lysimeter data:** Conduct on-ground experiments using lysimeters to obtain observed ET_0 values for rigorous model validation.
- **Geospatial analysis of ET_0:** Utilize GIS tools to map spatial variations in ET_0 across Annamalai Nagar, supporting region-specific agricultural planning.
- **Hybrid modeling approaches:** Combine empirical and physically-based models to create hybrid ET_0 models that leverage the strengths of both methods.

REFERENCES

[1]. Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements* (FAO Irrigation and Drainage Paper No. 56). FAO.

[2]. Hargreaves, G. H., & Samani, Z. A. (1985). Reference crop evapotranspiration from temperature. *Applied Engineering in Agriculture*, **1**(2), 96–99.

[3]. Monteith, J. L. (1965). Evaporation and environment. *Symposia of the Society for Experimental Biology*, **19**, 205–234.

[4]. Smith, M. (1992). *CROPWAT: A computer program for irrigation planning and management* (FAO Irrigation and Drainage Paper No. 46). FAO.

[5]. Sentelhas, P. C., Gillespie, T. J., & Santos, E. A. (2010). Evaluation of FAO Penman-Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canada. *Agricultural Water Management*, **97**(5), 635–644.

[6]. Shahidian, S., et al. (2013). Comparative study of different methods for estimating reference evapotranspiration in Portugal. *Water Resources Management*, **27**(10), 3115–3131.

[7]. Jensen, M. E., Burman, R. D., & Allen, R. G. (1990). *Evapotranspiration and irrigation water requirements* (ASCE Manuals and Reports on Engineering Practice No. 70). American Society of Civil Engineers.

[8]. Tabari, H. (2010). Evaluation of reference crop evapotranspiration equations in various climates. *Water Resources Management*, **24**(10), 2311–2337.

[9]. Irmak, S., et al. (2003). Reference evapotranspiration with hourly and daily data: III. Model comparisons. *Journal of Irrigation and Drainage Engineering*, **129**(6), 442–457.

[10]. Trajkovic, S. (2007). Hargreaves versus Penman-Monteith under humid conditions. *Journal of Irrigation and Drainage Engineering*, **133**(1), 38–42.

[11]. Kumar, M., & Reddy, M. J. (2018). Reference evapotranspiration modeling using soft computing

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25mar129

techniques. *Theoretical and Applied Climatology*, **131**(3-4), 1149–1162.
[12]. Lu, J., Sun, G., McNulty, S. G., & Amatya, D. M. (2005). A comparison of six potential evapotranspiration methods for regional use in the southeastern United States. *Journal of the American Water Resources Association*, **41**(3), 621–633.
[13]. López-Urrea, R., et al. (2006). Testing evapotranspiration equations using lysimeter observations in a semiarid climate. *Agricultural Water Management*, **85**(1-2), 15–26.
[14]. Donohue, R. J., Roderick, M. L., & McVicar, T. R. (2010). Can dynamic vegetation information improve the accuracy of Budyko's hydrological model? *Journal of Hydrology*, **390**(1-2), 23–34.
[15]. Yoder, R. E., Odhiambo, L. O., & Wright, W. C. (2005). Evaluation of methods for estimating daily reference crop evapotranspiration at a site in the humid southeast United States. *Applied Engineering in Agriculture*, **21**(2), 197–202.